Building a System Reliability Model for SSL Luminaires

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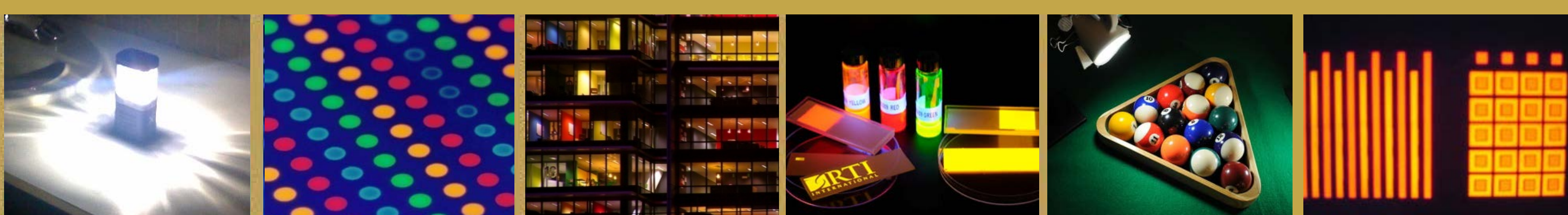
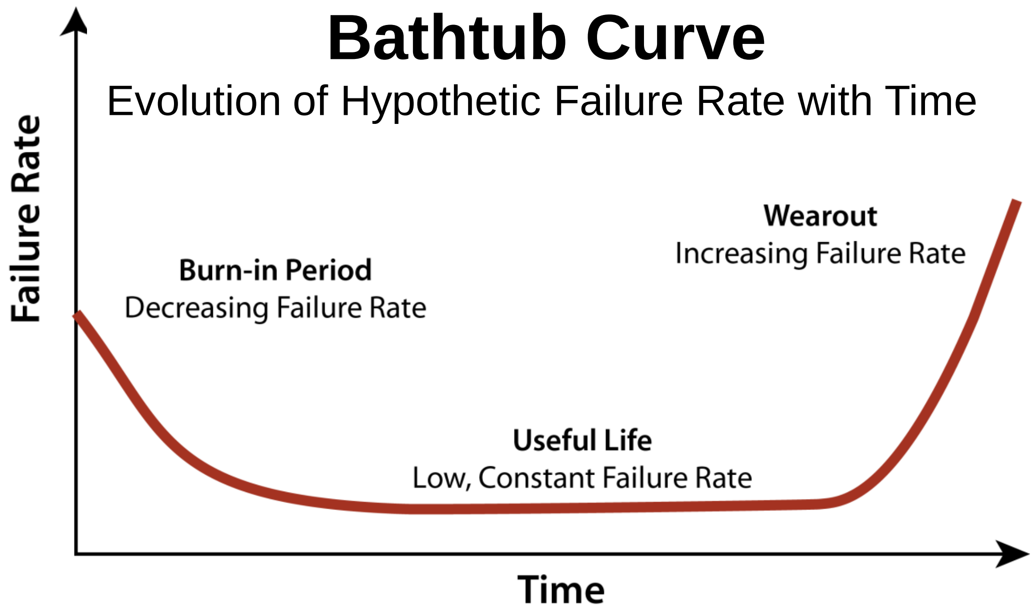
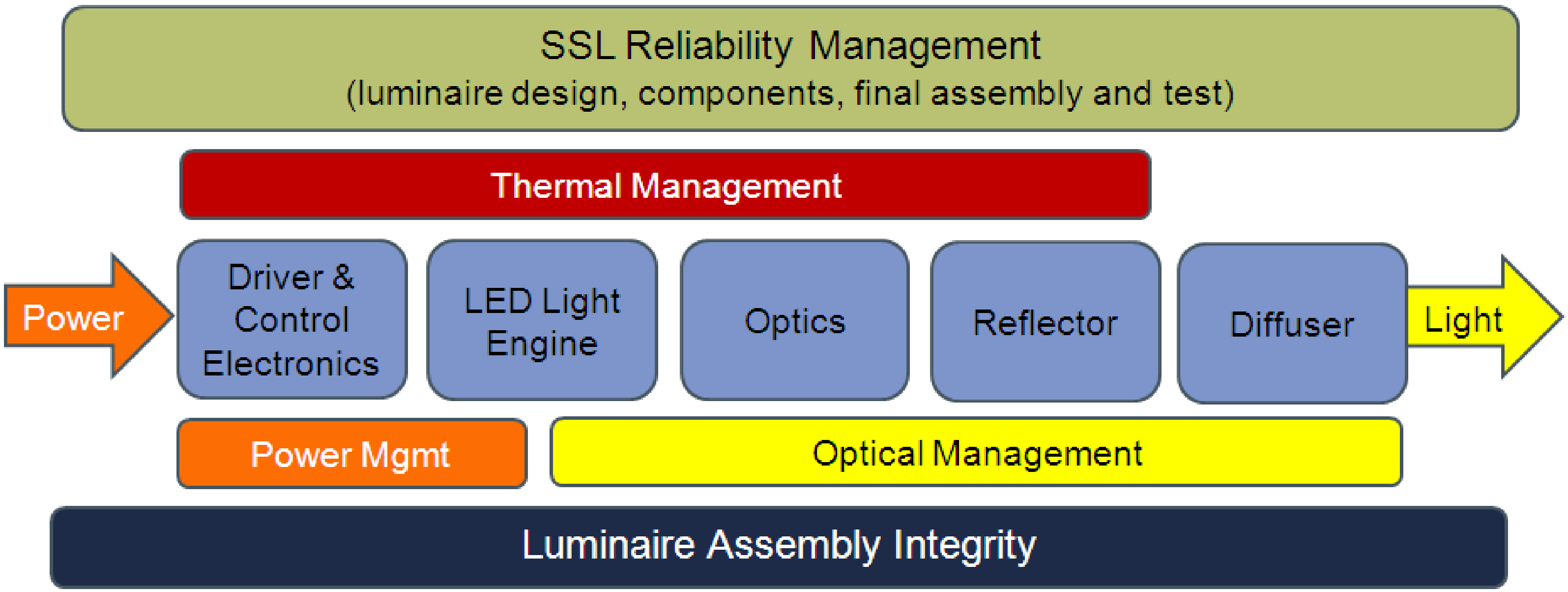


Background

- True reliability and lifetime of LED lighting systems are generally not known.
- Claims of long lifetimes in SSL systems are often based solely on LED lumen maintenance information.
  - Ignores system-level impacts
  - Customer experience may be different
- A model of luminaire reliability would aid the SSL luminaire manufacturers and end users.



SSL Luminaire System Reliability

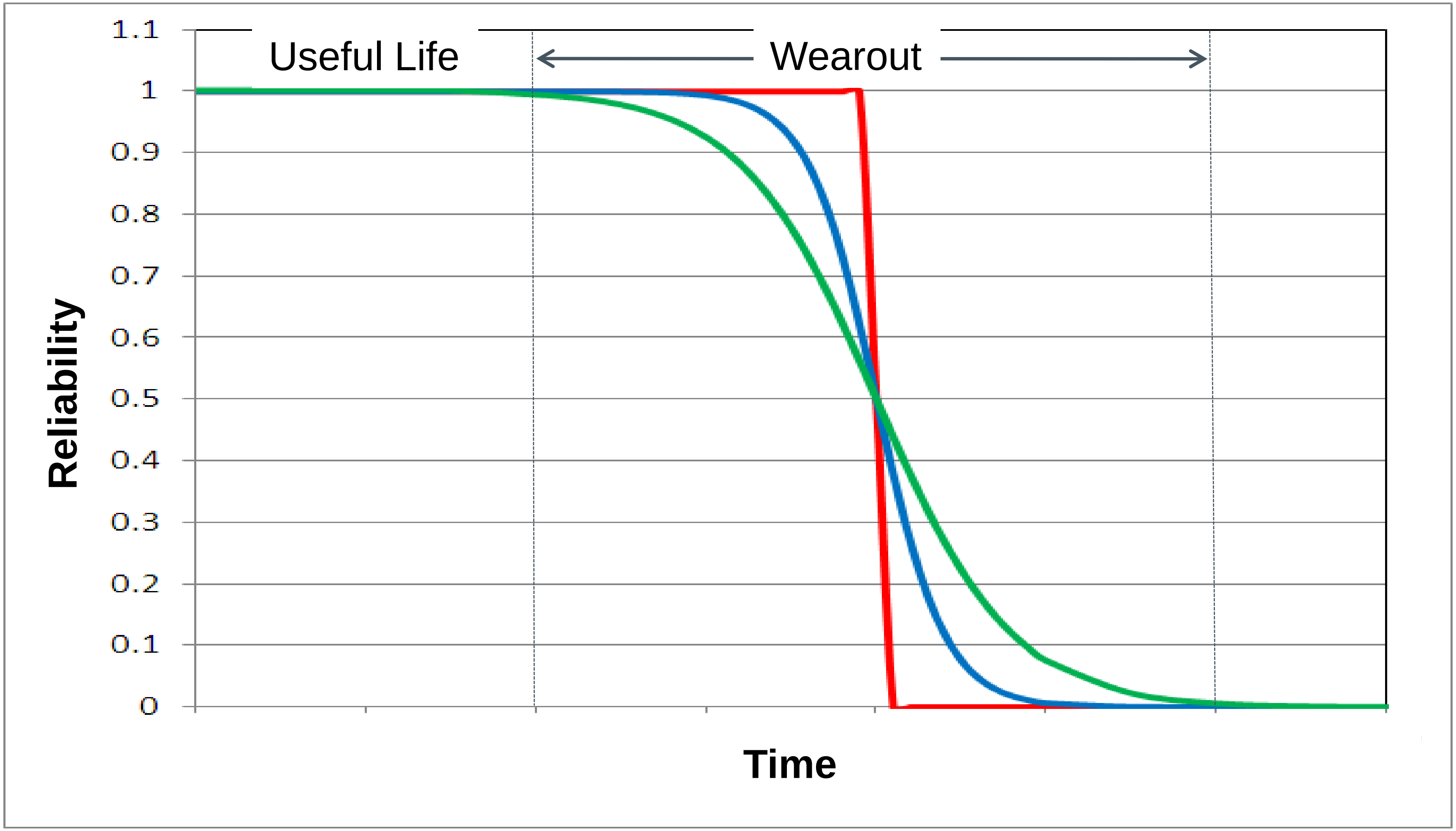


Source: Appalachian Lighting Systems, Inc.

FAILURE OUTCOMES

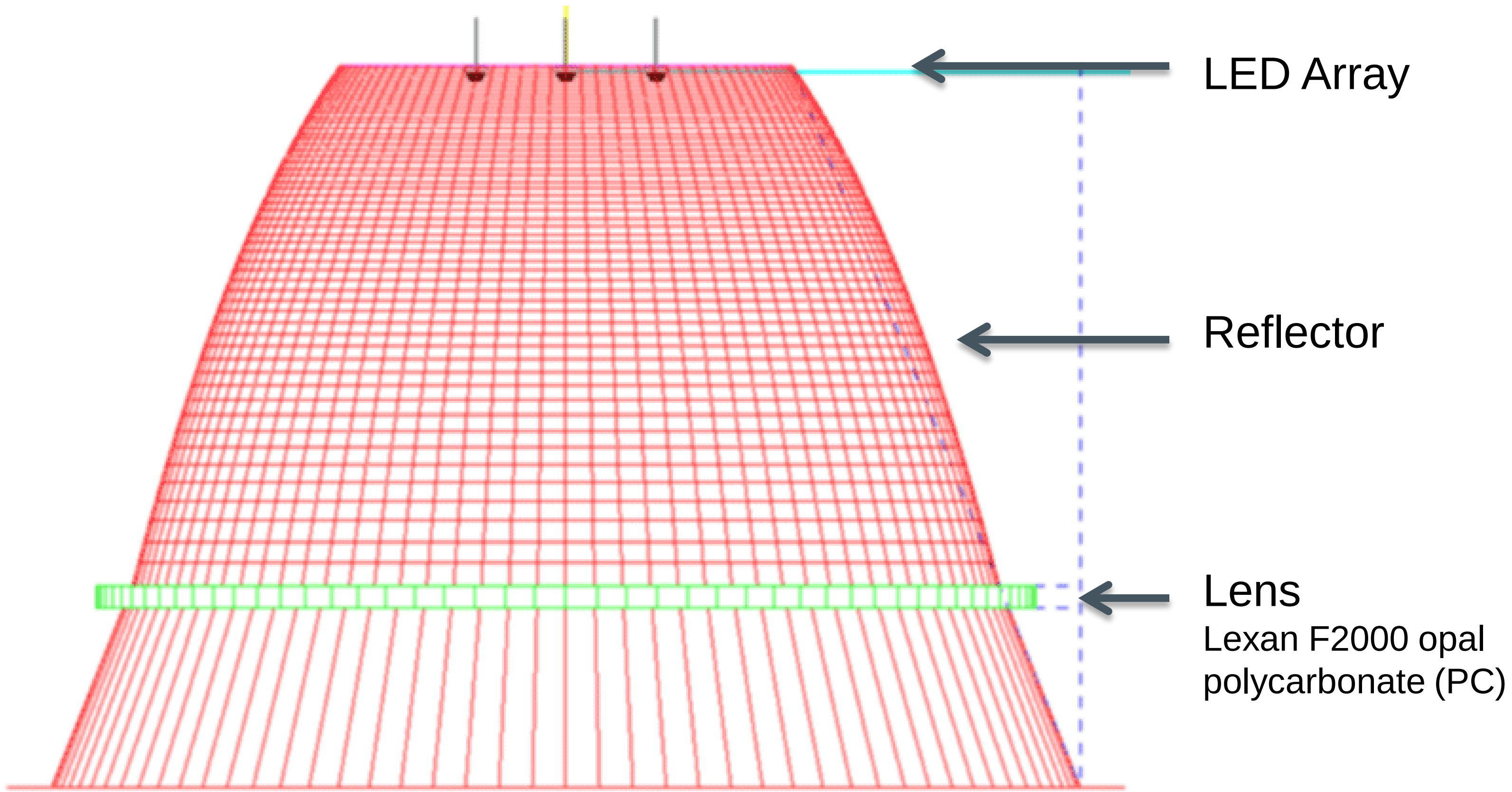
- **Catastrophic failure**—Complete failure of the device to produce light.
  - Associated mainly with power management components
- **Lumens maintenance**—Ability of a device to produce acceptable light output above a predetermined unacceptable level (e.g., L_{70}) for 50% of the population (B_{50}).
  - Associated mainly with optical management components
- **Color shift**
- **Reduced energy efficiency**

Failure Usually Does Not Happen All at Once



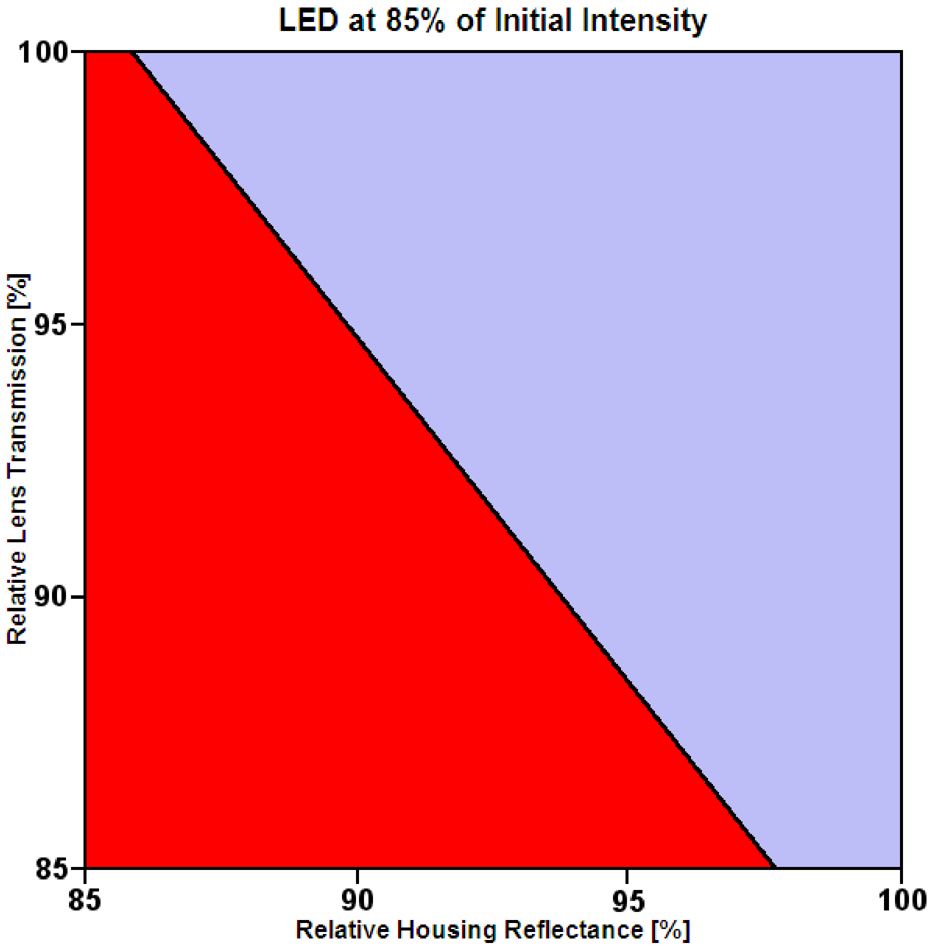
Reliability is the probability that a device will perform its intended function during a specified period of time <u>under stated conditions</u>.

Example of Impact of Changes in Optical Management System



Photometric simulation programs can provide insights into the impact of aging of the optical management sub-system.

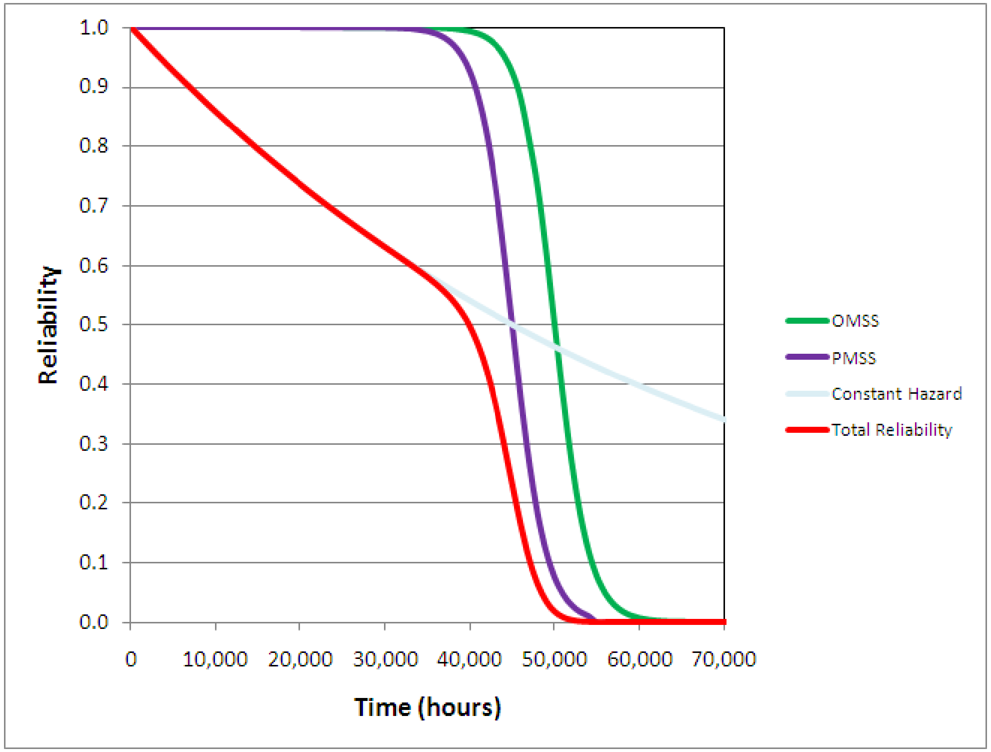
Sensitivity Analysis for Downlight Optical Management System



Small changes (~ 5-6%) over time in lens transmission and housing reflectance significantly reduces the luminous flux.

Model Development

- Optical management sub-system reliability will depend upon:
  - Materials
  - Overall luminaire design
  - Specified environment
- Power management sub-system reliability will depend upon:
  - Component derating
  - Thermal management
  - Power quality
- Both sub-systems can be designed for high reliability under controlled conditions.
- In the field, some conditions may negatively impact hazard rate and lead to failure.



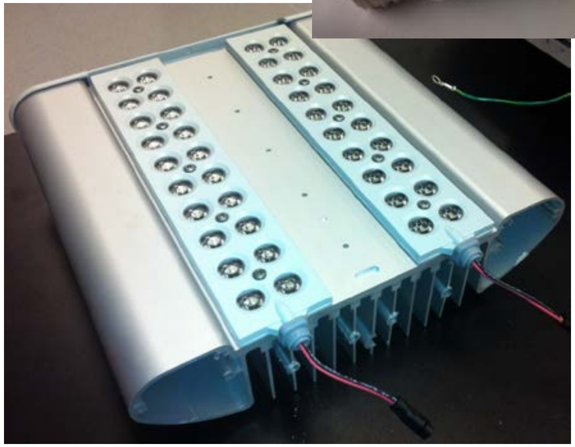
Failure in the Field

- Catastrophic failure can occur due to latent defects, harsh environments, poor installation, wrong product choice. Catastrophic failure be represented by a constant hazard rate.
- A number of potential causes for catastrophic failure that can occur at different stages in product life
  - Manufacturing issues
    - Die cracking
    - Solder interconnects
    - PCB
  - Materials limitations
    - Electrolytic capacitors
    - Gaskets
    - Cumulative damage (e.g., vibration)
  - Corrosion due to moisture ingress combined with ionics
  - Electrical surges/lighting strikes
  - Excessive ripple/dirty power

Challenges to Building a SSL Luminaire Reliability Model

- Multitude of design options for both the Optical Management Sub-System and Power Management Sub-System.
  - Focus initial model on a limited set of luminaire types – downlights & area lights
  - Leverage literature findings as a guide
  - Utilize “virtual” luminaires to understand impact of changes
- Hazard functions needs to be defined for both indoor and outdoor environments.
- Body of experimental data is needed.

Initial model is under development and will be available for limited use within 2 years.



Testing Methods

- A variety of components are used in constructing SSL luminaires, which can impact testing approach
  - LED and Driver
  - Plastics and metals
  - Solders and interconnects
- A number of environmental stressors can be used to accelerate failure
  - Temperature (Low and High)
  - Humidity
  - Duty cycle
  - Electrical ripple/surge
  - Salt fog/corrosives ingress
  - Vibration
  - Particulates
- Approach – start with limited set of extreme stressors

Phase 1 — Temperature, Humidity, Electrical Cycling

Luminaire failure modes identification through Highly Accelerated Life Testing (HALT)

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Phase 2 — Additional Stressors

Component level testing with additional environmental stressors

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Phase 3 — Additional Stressors

Testing at the Power Management and Optical Management Sub-System Levels

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Phase 4 — Stressors

Targeted Accelerated Life Tests (ALT) at the luminaire level

Developed in collaboration with LED Systems Reliability Consortium.

Conclusions and Acknowledgements

- To accommodate the rapid evolution of SSL technologies and fully realize the energy savings potential of SSL technologies, there is a widespread need in the lighting industry for a SSL luminaire reliability model.
- A systems-level approach needs to be used to understand SSL lumen reliability. LM-80/TM-21 data on LEDs is not sufficient.
- Initial testing has indicated that SSL luminaires can withstand extreme environments. Much more testing is required to fully understand SSL systems reliability.
- A critical component in developing this model is gathering information from the lighting industry.
- Acknowledgements
  - U.S. Department of Energy for providing funding for this work
  - Partners: Auburn University, Cree, SAS Institute, PPG Industries
  - LED Systems Reliability Consortium

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